The Magnetic Reconnection Code: Center for Magnetic Reconnection Studies

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INTRODUCTION

The Center for Magnetic Reconnection Studies (CMRS) was a multi-institutional consortium, originally involving three academic institutions: the University of Iowa (Principal Investigator: Professor A. Bhattacharjee), the University of Chicago (Principal Investigator: Professor R. Rosner), and the University of Texas at Austin (Principal Investigator: Professor R. Fitzpatrick) The CMRS was located at and administered from the University of Iowa initially, and moved to the University of New Hampshire in the last year of its funding. The last year of the funding was extended under a no-cost extension agreement. The CMRS was funded under the auspices of the SciDAC (Scientific Discovery with Advanced Computing) program.

It was proposed that the principal computational product of the proposed research program was a single code, called the Magnetic Reconnection Code (MRC). This has been accomplished. The MRC is a fully three-dimensional compressible Hall MHD code (of which resistive/viscous MHD is a special case) with options to run in slab, cylindrical, and toroidal geometry. It has options for equations of state and boundary conditions that will enable us to carry out free as well as forced reconnection studies. The code is modular, with the flexibility to change algorithms if necessary, and use Adaptive Mesh Refinement (AMR). It is massively parallel, using extant libraries to achieve portability and scalability on a variety of different message-passing parallel computers. The MRC is a unique tool of high-performance computing and will be applied to a broad range of physical problems involving collisional as well as collisionless magnetic reconnection in astrophysical, laboratory/fusion, and space plasmas. In addition to the MRC, we have developed a fully three-dimensional particle-in-cell (PIC) code, ExPIC, which was not promised in our proposal, but represents additional value added to this research program. ExPIC enables us to investigate the kinetic physics of reconnection.

PUBLICATIONS

The MRC and ExPIC have been used for fusion, space, and astrophysical applications. The papers completed under the auspices of this research program are listed below:

1. Scaling of collisionless reconnection, X. Wang, A. Bhattacharjee and Z. W. Ma, Physical Review Letters **87**, 265003 (2001).

2. Equilibrium and stability of strong vertical magnetic fields at the Galactic center, B.

Chandran, Astrophysical Journal **562**, 737 (2001).

3. Electrostatic degrees of freedom in non-Maxwellian plasma, F. Skiff, H. Gunell, A. Bhattacharjee, C. S. Ng and W. A. Noonan, Physics of Plasmas **9**, 1931 (2002).

4. Radio-wave propagation through a medium containing electron-density fluctuations described by an anisotropic Goldreich-Sridhar spectrum, B. Chandran and D. Backer, Astrophysical Journal **576**, 176 (2002).

5. Hall MHD ballooning instability in the magnetotail, P. Zhu, A. Bhattacharjee and Z. W. Ma, Physics of Plasmas **10**, 249 (2003).

6. WIND observations pertaining to current disruptions and ballooning instabilities during substorms, L.-J. Chen, A. Bhattacharjee, K. Sigsbee, M. Fillingim, G. Parks and R. Lin, Geophysical Research Letters **30**, 1335, doi:10.1029/2002GL016317 (2003).

7. Acceleration of energetic particles by slow magnetosonic modes in strong anisotropic compressible magnetohydrodynamic turbulence in the presence of strong pitch-angle scattering," Astrophysical Journal **599**, 1426 (2003).

8. Anisotropic fluid turbulence in the interstellar medium and solar wind (Invited Paper at the 44th Annual Meeting of the Division of Plasma Physics of the American Physical Society, Orlando, Florida, November 11-15, 2002), C. S. Ng, A. Bhattacharjee, K. Germaschewski and S. Galtier, Physics of Plasmas **10**, 1954 (2003).

9. Anisotropic weak whistler wave turbulence in electron magnetohydrodynamics, S. Galtier and A. Bhattacharjee, Physics of Plasmas **10**, 3065 (2003).

10. Wave driven magnetic reconnection in the Taylor problem, R. Fitzpatrick, A. Bhattacharjee, Z.-W. Ma, and T. Linde, Physics of Plasmas **10**, 4284 (2003).

11. Recent developments in collisionless reconnection theory: applications to laboratory and astrophysical plasmas, A. Bhattacharjee, Z. W. Ma, and X. Wang, in *Turbulence and Magnetic Fields in Astrophysics*, edited by E. Falgarone and T. Passot, Springer-Verlag Lecture Notes in Physics (Springer-Verlag, Berlin Heidelberg, 2003), pp. 351-375.

12. Complete spectrum of kinetic eigenmodes for plasma oscillations in a weakly collisional plasma, C. S. Ng, A. Bhattacharjee and F. Skiff, Physical Review Letters **92**, 065002 (2004).

13. Finite-k_y ballooning instability in the near-earth magnetotail, P. Zhu, A. Bhattacharjee, and Z. W. Ma, Journal of Geophysical Research **109**, A11211, doi:10.1029/2004JA010505 (2004).

14. The spherical tearing mode, S. Hu, A. Bhattacharjee, J. Dorelli, and J. M. Greene, Geophysical Research Letters **31**, 119806, doi: 10.1029/2004GL020977 (2004).

15. Convection in galaxy-cluster plasmas driven by active galactic nuclei and cosmic-ray buoyancy, B. Chandran, Astrophysical Journal **616**, 169 (2004).

16. Stochastic relativistic shock-surfing acceleration, B. Chandran and N. Bessho, Astrophysical Journal **613**, 622 (2004).

17. A review of the theory of incompressible MHD turbulence, B. Chandran, Astrophys. Sp. Sci. **292**, 17 (2004).

18. Reacceleration of energetic particles by large-scale compressible magnetohydrodynamic turbulence in extragalactic radio sources and the interstellar medium, B. Chandran and J. Maron, Astrophysical Journal **603**, 23 (2004).

19. Thermal conduction in galaxy-cluster plasmas and the divergence of neighboring magnetic field lines in strong magnetohydrodynamic turbulence, B. Chandran and J. Maron, Astrophysical Journal **602**, 170 (2004).

19. The divergence of neighboring magnetic field lines and fast-particle diffusion in strong magnetohydrodynamic turbulence, with application to thermal conduction in galaxy clusters, J. Maron, B. Chandran, and E. Blackman, Physical Review Letters **92**, id. 045001 (2004).

20. Impulsive magnetic reconnection in the Earth's magnetotail and solar corona, A. Bhattacharjee, in *Annual Review of Astronomy and Astrophysics*, edited by R. Blandford, G. Burbidge, and A. Sandage, Vol. 42, pp. 365-84 (2004).

21. Current singularities: drivers of impulsive reconnection (Invited Paper at the 45th Annual Meeting of the Division of Plasma Physics of the American Physical Society, Albuquerque, New Mexico, October 27-31, 2003), A. Bhattacharjee, K. Germaschewski, and C. S. Ng, Physics of Plasmas **12**, 042305 (2005).

22. Collisionless reconnection in an electron-positron plasma, N. Bessho and A. Bhattacharjee, Physical Review Letters **95**, 245001 (2005).

23. Bernstein-Greene-Kruskal modes in a three-dimensional plasma, C. S. Ng and A. Bhattacharjee, Physical Review Letters **95**, 245004 (2005).

24. Anisotropic wave turbulence in electron MHD, S. Galtier and A. Bhattacharjee (Invited paper at the 32nd European Physical Society Conference on Plasma Physics), Plasma Physics and Controlled Fusion **47**, B691 (2005).

25. Turbulent Heating of Galaxy-Cluster Plasmas, T. Dennis and B. Chandran, Astrophysical Journal **622**, 205 (2005).